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National building stock model for evaluating the impact of different retrofit measures

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National building stock model for evaluating the impact of different retrofit measures

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Abstract. In this study, a methodology was developed to evaluate different retrofit strategies, which allows an estimation of the current and future thermal space heating demand of the approximately 1.8 million residential buildings in Switzerland. The approach is based on a building stock dynamics model that considers new buildings, replacement buildings, demolitions, as well as past and current rates of energy-related retrofits. Different potential retrofit strategies are applied to evaluate their impact on reducing space heating demand. The results show the effectiveness of the distinct retrofit strategies in reaching the target reduction and emphasize the differences in the resulting annual retrofit rates. The simulated specific retrofit rates can serve as a basis for developing building retrofit measures at the national level, as well as for informing the next generation of regulations.

Keywords: retrofit strategies, building stock models

1. Introduction

The building sector accounts for nearly a third of operational energy demand and greenhouse gas (GHG) emissions globally [1]. These are influenced by the building stock characteristics, i.e. the proportional representation of buildings by type/age and their thermal insulation standards. In Europe, approximately half of the building stock is older than 50 years, with a large share of buildings built according to limited, old insulation standards [2]. As a result, building envelope retrofits present a high potential in reducing operational (direct) GHG emissions. In this study, a methodology for the evaluation of different retrofit strategies was developed, which allows the estimation of the current and future thermal space heating demand. Considering a Swiss case study, a methodological approach is used to evaluate the effect of mandatory retrofit measures on reducing the national residential space heating demand. By focusing on the impact of different retrofit options, we overcome the often simplified perspective on building retrofit that does not distinguish between different retrofit options and the corresponding retrofit rates.

The Swiss Energy Perspective 2050+ [3] estimates a 20TWh (thermal) target reduction for space heating for the net zero case. With residential buildings accounting for 64% of space heating demand [4], the expected target reduction for residential buildings investigated here is proportionally attributed (12.8TWh).

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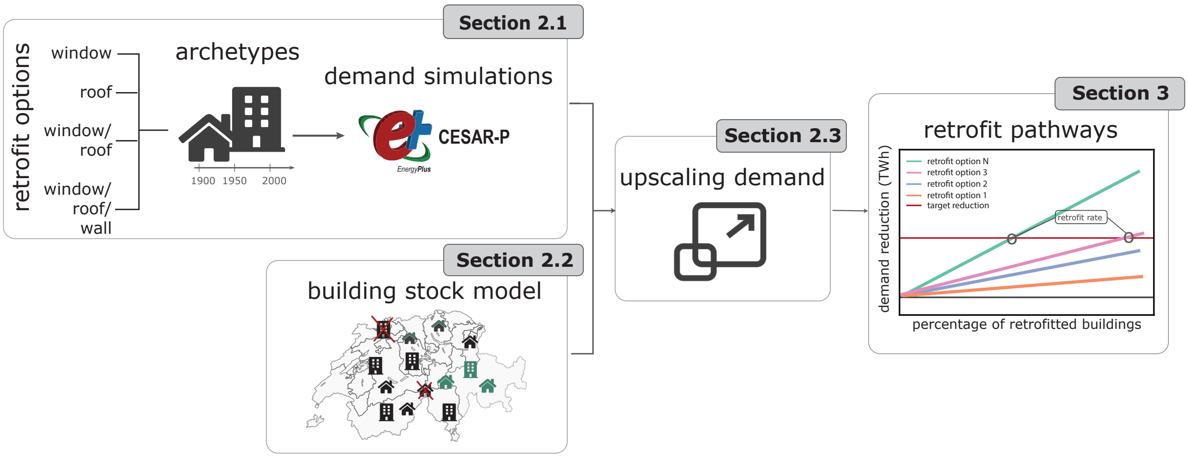

Figure 1. Process flow

2. Methodology

The method comprises (1) bottom-up energy demand simulation of building archetypes including different retrofitting options, (2) building stock dynamics, and (3) upscaling of the archetype results to the national scale for different retrofit scenarios. Figure 1 below summarizes the approach and indicates the corresponding sections where they are presented in more detail.

2.1. Simulation of archetypical buildings and their retrofits

In the first step, we identify 240 building archetypes to represent the Swiss residential building stock of around 1.8 million buildings [5]. Each archetype is simulated using a dynamic urban simulation tool (CESAR-P/EnergyPlus software) [6, 7]. To evaluate the effectiveness of various retrofit measures on the energy demand of each archetype, the simulation is then repeated for various building envelope retrofits, comprising single building elements and their combinations (windows, roof, window-roof, and windows-roof-wall). For the retrofits, we assume that minimum standards set by the Swiss Association of Engineers and Architects (SIA) are met ($0.25W/m^2K$ for opaque building elements, $1W/m^2K$ for glazing) [8]. Today's standard values are assumed to gradually improve towards higher standards prescribed for new buildings ($0.17W/m^2K$ for opaque building elements, $1W/m^2K$ for glazing) for future years until 2050. The method does not consider possible energy performance gaps, which have been shown to underestimate the impact of improved energy efficiency on reducing demand due to the combined prebound and rebound effect [9]. The resulting specific heating energy demand of the current and renovated archetypes, as well as the new construction, are then used as an input to the stock dynamics model described below.

2.2. Modeling of the evolution of the Swiss building stock under different scenarios

In this step, we implement a model to approximate the evolution of the current building stock according to the projected trends in additional, demolished, and retrofitted buildings from EP2050+. This includes first quantifying new and demolished buildings in terms of their energy reference area for a set of future time steps, and applying those to the current building stock. Additionally, a natural retrofit rate of 1% per year, i.e. reflecting retrofits which would occur independently of retrofit obligation measures (e.g. age-related retrofits), is also applied. For the natural retrofit rate, the following assumptions are made: for 40% of the buildings, a full retrofit (window-roof-wall-ground) is carried out, for 20% of the buildings, a window-wall-roof retrofit and for 40% of the buildings, a window-roof retrofit [3]. These retrofits are considered first in the retrofit paths. The resulting future building stock—comprising remaining, retrofitted, and newly constructed buildings together with their corresponding archetypes—is used in the subsequent step to evaluate the impact of different retrofit obligations. Excluding demolished and newly added buildings, candidates for retrofit are based on GEAK classification. Buildings classified as poorly performing (i.e. belonging to the F/G GEAK class) are considered for retrofit, according to the procedure outlined in Sec. 2.2.1 below.

2.2.1. Selection criteria for retrofitting The building energy certificate of the cantons (GEAK) [10] allows the standardised assessment of the building envelope and the overall energy efficiency of Swiss buildings. This energy certificate is not systematically assessed and mostly voluntary, even though a GEAK assessment is compulsory for some cantons in case of building retrofit. Each building can be assigned to a GEAK class (ranging from the highest efficiency class A to the lowest efficiency class G) with help of the indicator $R_{H,eff}$, which is calculated according to SIA [11] as follows:

$$R_{H,eff} = \frac{Q_{H,eff}}{Q_{H,li}} * 100 \tag{1}$$

where $Q_{H,eff}$ is the actual specific annual thermal energy demand of each building (in kWh/m^2), and $Q_{H,li}$ is the building category specific limiting value according to SIA 380/1:2016 (Table 2) [8]. $Q_{H,li}$ and $Q_{H,eff}$ are calculated as

$$Q_{H,li} = [Q_{H,li0} + \Delta Q_{H,li}\frac{A_{th}}{A_E}] * f_{cor} \tag{2}$$

$$Q_{H,eff} = D_S * \frac{A_{th}}{A_E} \tag{3}$$

where $Q_{H,li0}$ and $\Delta Q_{H,li}$ are building category specific values provided by Table 6 according to SIA 380-1/2016, A_E is the energy reference are, A_{th} is the building envelope area and D_S is the actual energy demand, which corresponds in our case to the simulated energy demand [8]. A simplified approach is chosen to calculate A_{th} (as opposed to SI 380-1/2016) by summing up all external wall areas, all roof areas and the floor area. Simplified building geometry based on a level-of-detail (LOD) 1 (i.e. flat roofs) representation is used. As cluster-specific energy demands are assigned to each building (see Sec. 2.1), also cluster-specific ratios of the thermal hull and the energy reference area ($\frac{A_{th}}{A_E}$) are calculated and used, i.e. not actual properties are used for each building. As the provided limiting values in SIA 380/1:2016 are based for a mean annual temperature of 9.4°C, they are adapted depending on the annual mean temperature (t_{avg}).

$$f_{cor} = 1 + (9.4°C - t_{avg}) * 0.06 * K^{-1} \tag{4}$$

Additionally, a correction is made due to the assumed indoor temperature of 20°C in the original formulation, whereas 21° is used in the simulations performed here (a difference of approximately 6% [12]). Based on this criteria, the current distribution of all single- and multi-family homes according to the assigned GEAK classes is determined and suitable candidates for retrofit selected.

2.3. Scaling up the archetypal results to derive the Swiss energy demand)

Finally, the evolution in the Swiss building stock is transformed to the corresponding evolution of the Swiss space heating demand according to the assigned building archetypes. Different retrofit measures are implemented and their impact on the Swiss space heating demand is evaluated.

3. Results and discussion

The various savings potentials and retrofit rates for different retrofit options and combination of options (strategies) are presented in the sections below.

3.1. Building level results

Figure 2 shows the current specific space heating demand by building type and building age. Space heating demand reduction depending on the retrofit option are shown hatched. The values are averaged according to age category and building type.

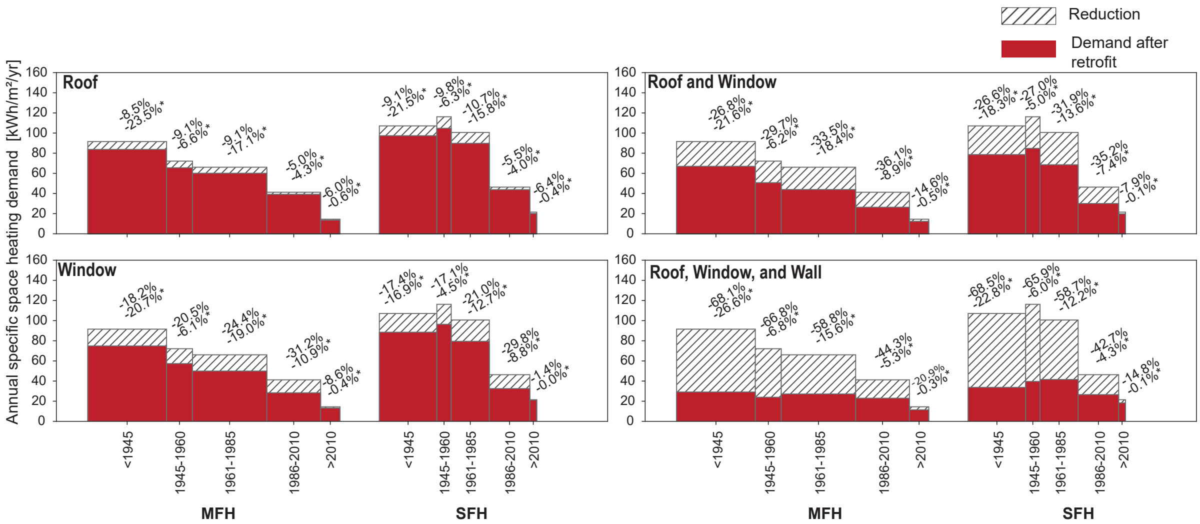

Figure 2. Reduction of the specific space heating demand of the different retrofit options, building types (single- and multi-family house) and building age classes. The width of the bars reflects the proportional representation of buildings in Switzerland. The weighted energy savings of a retrofit are shown by the shaded area. Potential contribution of the specified building stock segment in reducing the total space heating demand is marked with an asterisk. The calculations were made assuming SIA limit values.

3.2. Retrofit candidates

Here we consider potential candidates for retrofit according to the GEAK classification. Based on the approach outlined in Sec. 2.2.1, the distribution of all single- and multi-family homes according to the assigned GEAK classes, including corresponding average specific energy demands, is shown in Figure 3. Based on this, 60% of remaining buildings (i.e. excluding demolished and newly added buildings) are classified as F/G and considered in the analysis of potential retrofit pathways presented in Sec. 3.3.

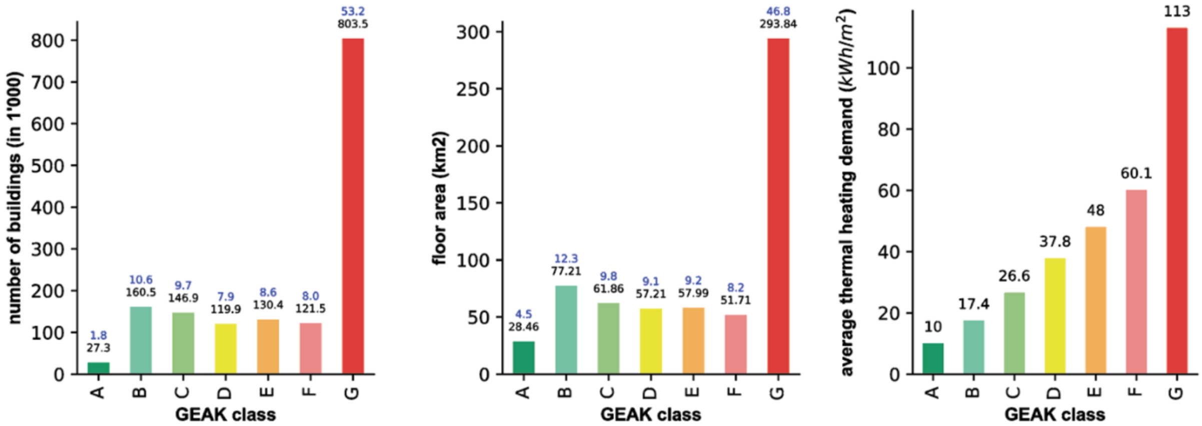

Figure 3. Simulated allocation of GEAK class for all residential buildings. Left: Number of building assigned to each GEAK class for the current situation (relative distribution provided as blue numbers); Middle: distribution of floor area of the different GEAK classes; Right: specific thermal heating energy demand per GEAK class. Based on the calculation with archetypes, about 60% of buildings belong to F/G class. When compared to the GEAK certificates, this number appears to be an overestimate, which could be explained by high infiltration rates assumed for old buildings. This number is therefore to be understood as an approximation.

3.3. Retrofit pathways

Figure 4 shows space heating demand reduction pathways considering different retrofit options. The retrofit options are compared based on their ability to reach the target reduction (red line) and the resulting annual retrofit rate. We also consider the impact that the background retrofit rate of 1% per year has on the effectiveness of different retrofit strategies in reaching the target reduction.

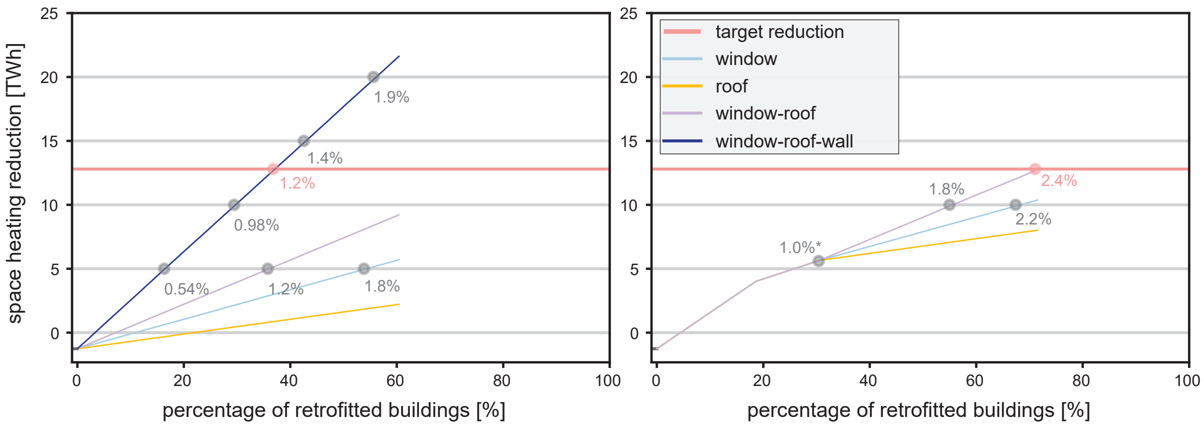

Figure 4. Savings in space heating demand in TWh (y-axis) without (left figure) and with (right figure) a natural retrofit rate of 1% per year. The retrofit paths show the savings in space heating demand. The x-axis shows the percentage of buildings that are retrofitted (excluding demolished and newly added buildings). Annual retrofit rate is shown for the target reduction (in red) along with other demand reduction stages for the timeframe from 2020 to 2050.

The age-related background retrofit rate is carried out first according to the assumptions outlined in Sec. 2.2 in the following order: full, window-wall-roof, window-roof. The transition between the two deeper retrofits is negligible, while a transition to the window-roof retrofit shows an abrupt change in slope (at 18% of retrofitted buildings). Since these retrofits include some buildings outside of F/G rating, the overall percentage of retrofitted buildings is higher.

4. Concluding remarks and future work

The results show the effect of various retrofit measures—for individual building elements and their combinations—on reducing the national space heating demand in residential buildings. The comparison is based on whether a particular retrofit strategy is sufficient to reach the target reduction of the building stock, and if so, the corresponding annual retrofit rate. We demonstrate that the impact of different retrofit measures clearly differs and therefore practitioners and researchers need to be specific when talking about retrofit rates.

We find that an optimal strategy would be to focus on the energy performance due to the heterogeneous building stock where retrofits may have taken place in the past. However, such targeted building retrofit may not be feasible due to the lack of available performance data. We show that retrofit obligations focusing on single building elements are unable to reach the target reduction, whereas the reduction can be met with the combination of the two most common retrofits (window-roof). Nevertheless, the retrofit rate is nearly halved when a deeper retrofit (window-roof-wall) is considered (from 2.4 to 1.2%). A policy recommendation that can be derived from this work is to prioritize and incentivize these two retrofit options for low-efficiency buildings. Future work will need to consider the impact of changing occupant behavior in response to the retrofit (prebound and rebound effect) on the effectiveness of different retrofit measures in reducing demand.

Acknowledgements

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